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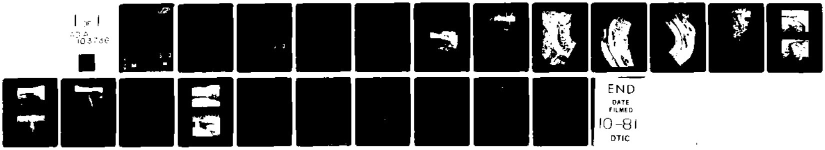

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Special Report 81-9

May 1981

ICE JAM PROBLEMS AT OIL CITY, PENNSYLVANIA

David Deck and Gordon Gooch

Prepared for
U.S. ARMY ENGINEER DISTRICT, PITTSBURGH
By

UNITED STATES ARMY CORPS OF ENGINEERS
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE, U.S.A.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Special Report 81-9

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
ICE JAM PROBLEMS AT OIL CITY, PENNSYLVANIA

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
David Deck and Gordon Gooch

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire 03755

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
U.S. Army Engineer District
Pittsburgh, Pennsylvania

12. REPORT DATE
May 1981

13. NUMBER OF PAGES
22

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Flood control
Ice jams
Ice prevention

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Oil City, Pennsylvania, is at the confluence of Oil Creek and the Allegheny River. The business district lies within the flood plain of Oil Creek, and as of the winter of 1980, 25 ice jam flooding events had occurred since the mid-1800's.

An investigation was done to determine why Oil City was subject to perennial ice jams and nearly biennial ice jam floods. Ice conditions were analyzed and it was determined how and why the ice jams occurred. By controlling where the initial ice cover forms, Oil City's ice jam floods can be alleviated. Ice control structures will be used to encourage the early formation of ice cover and hence eliminate frazil ice. This will greatly reduce the amount of ice which currently develops in both Oil Creek and the Allegheny River.

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PREFACE

This report was prepared by David Deck, Research Hydraulic Engineer, and Gordon Gooch, Civil Engineering Technician, Ice Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. The study was supported under an agreement with the city of Oil City, Pennsylvania, *Oil Creek Flooding and Ice Jamming Project*, 10 June 1980.

The report was technically reviewed by Dr. G. Ashton and Mr. J. Wuebben of CRREL.

Historical data were provided by the Pittsburgh District, Army Corps of Engineers and by the City of Oil City; their efforts are appreciated with special thanks to Mr. James Hicks of Oil City.

CONTENTS

ILLUSTRATIONS

TABLES

ICE JAM PROBLEMS AT OIL CITY, PENNSYLVANIA

David Deck and Gordon Gooch

INTRODUCTION

Oil City, located in Venango County in northwestern Pennsylvania, has been plagued by ice jams and ice-related flooding since the earliest recorded event in the mid-1800's (Table 1). These floods have caused extreme hardships for the community. H.T. Barnes's 1928 publication titled *Ice Engineering* documents the 1926 ice jam. The last major ice jam flood occurred in February 1979. Within hours Oil Creek jammed and flooded the city with water and ice. The damage cost Oil City an estimated $800,000. Figures 1 and 2 show the result of the 1970 ice jam, a similar event. The heavy economic losses and two deaths over the years indicate the severity of Oil City's problem.

Oil City lies within the Pittsburgh District of the Corps of Engineers, who requested that the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) apply their expertise in ice to the Oil City problem.

SITE CONDITION

Allegheny River

The Allegheny River flows westward through Oil City and joins the Monongahela River in Pittsburgh to form the Ohio River. The average bed slope at Oil City is 5.6×10^{-4} m m^{-1} and the river width ranges from 120 m (400 ft) to 240 m (800 ft). The average annual discharge at Oil City is 200 m^3 s^{-1} (7,000 cfs). The city is divided by the river (Fig. 3 and 4) and is developed on both the north and south banks. The city limits extend from river mile 130.4 to 132.2, with the confluence with Oil Creek at mile 131.35. While the river remains within its banks during high discharge periods, its backwater can cause the creek to have overbank flooding. In about 1950 the Oil City Sand and Gravel Company began to commercially extract gravel from the river bed. Extensive dredging was done between river mile 129.1 and 131.0 and at one time extended as far as river mile 132.0. The dredging operation was halted about 1970 when the Allegheny River was included under the Wild and Scenic Rivers Act. Kinzua Dam, a flood control structure, was built in 1967 by the Army Corps of Engineers. It is located at river mile 197.4. Kinzua maintains a minimum flow of approximately 42 m^3 s^{-1} (1500 cfs) in the Oil City area.

Oil Creek

Oil Creek is a major tributary of the Allegheny. It flows southward through Oil City with a mean flow of approximately 14 m^3 s^{-1} (500 cfs) and a bed slope of 1.9×10^{-3} m m^{-1}. Oil City's business area is on the east floodplain of the creek (Fig. 5 and 6).

PLAN OF STUDY

As initially conceived, our effort was separated into two phases. The objective of Phase I was to collect sufficient field and historical data to accurately define the problems and to propose possible solutions to relieve the severity of Oil City ice jam flooding. This work was completed in the first year. Phase II was to be a physical hydraulic model study to evaluate possible damage mitigation measures. After completing Phase I, however, we determined that Phase II was not necessary. Appropriate ice control techniques had already been developed.

DATA ACQUISITION

Initial field work began on 7 January 1980, when personnel from CRREL visited the Pittsburgh District office of the Corps of Engineers

Table 1. Ice jam floods in Oil City, Pennsylvania. A 100-yr Allegheny River stage of 18 ft represents overbank flow in Oil Creek.

Date	Allegheny River Stage (ft)	Date	Allegheny River Stage (ft)
March 1866	18+	23 January 1957	18 4
March 1883	18+	22 January 1959	21 8
26 March 1913	25 5	31 March 1960	19 6
17 February 1917	26 0	14 March 1962	18 6
17 March 1920	23 6	8 February 1965	19 5
22 March 1926	28 1	11 February 1966	18 0
27 February 1936	21 5	17 January 1969	18 5
25 January 1937	21 3	22 January 1970	21 0
5 March 1941	18 0	21 February 1971	19 3
25 February 1945	24 0	27 January 1976	21 2
23 March 1948	23 0	5 March 1977	19 6
1 January 1952	20 3	25 February 1979	21 0
8 March 1956	22 5		

Figure 1. Ice jam in Oil Creek, January 1970.

and Oil City to gather all pertinent ice jam flooding data. These data provided a good general overview of the area and its previous troubles.

Ice data collection began on 5 February 1980 and continued through 12 March 1980. Ice data were collected by drilling approximately 150 sample holes through the ice. These samples were taken at 20 different cross sections on both the Allegheny River and Oil Creek. In addition, samples were taken at random locations. At each sample hole we measured the solid ice thickness, the amount of frazil deposition, the depth of flow under the ice cover and the flow velocity. Appendix A depicts some representative cross sections of both the river and the creek.

We also attempted remote sensing of Allegheny River ice conditions using a radar system mounted on a Coast Guard helicopter. The Allegheny River in Oil City had an unknown radar interference source which obscured the signal, producing poor results. Oil Creek proved to be

Figure 2. Overbank flooding in the Oil City business district resulting from the 1970 ice jam.

inaccessible to the helicopter due to its many wire crossings, and therefore no radar work was possible.

Other important sources of information were discussions and correspondence with city officials and concerned residents of Oil City. This provided a historical perspective and a knowledge of the physical characteristics of ice problems in the area from 1866 to 1979.

This information, along with other river ice studies, allowed us to understand why and where the initial ice cover forms and to interpret the entire ice cover history for 1980.

ICE CONDITIONS

Formation

Under present conditions, initial ice cover formation occurs in the vicinity of Allegheny River mile 129.2. As shown in Figure 3c, there is an island at mile 129. The main flow of the river travels to the right of this island, with extremely low flows and shallow depths on the left (looking downstream). This allows shore-fast or border ice to form along the bank and on the many rock protrusions in the flow of the left channel.

The dredging between miles 129.1 and 129.5 occurred only in the left half of the river bed (Fig. A1 and A2). Water in this dredged area is approximately 6.1 m (20 ft) deep. A shallow shelf, with water depths of 0.6-1.2 m (2-4 ft), extends from the right bank throughout this reach. Shore-fast ice also forms here and for a time leaves approximately one-third of the river as open water.

During a cold spell [two or more days of -18 to -12°C (0° to 10°F) temperature], massive amounts of frazil ice are generated in the upper reaches of the river. The volume is estimated to be about 1.9×10^5 m^3 day^{-1} (2.5×10^5 yd^3 day^{-1}). The ice reaching the dredged pool is mainly in the form of large floating pans of frazil slush. When it reaches the river constriction near mile 129.2, it arches or bridges across the opening and forms the initial ice cover. The dredged area then acts as an ice collector.

The ice cover progresses upstream until it reaches the confluence with Oil Creek, where it encounters highly turbulent flow (Fig. 7). A stable ice cover cannot form over this reach of rapids. Internal failure occurs in the downstream ice cover, and it shoves and thickens as shown in Figures 8 and 9. This process continued during January of 1980 until 50-60% of the cross-sectional area in the deep pool was full of ice (Fig. A3 and A4).

The accumulation of ice in the dredged pool increased the resistance to flow, raising the water level at the confluence by 1.2-1.8 m (4-6 ft). This rise in stage effectively drowned the rapids, which reduced flow velocities and allowed the ice cover to proceed quickly up the river and

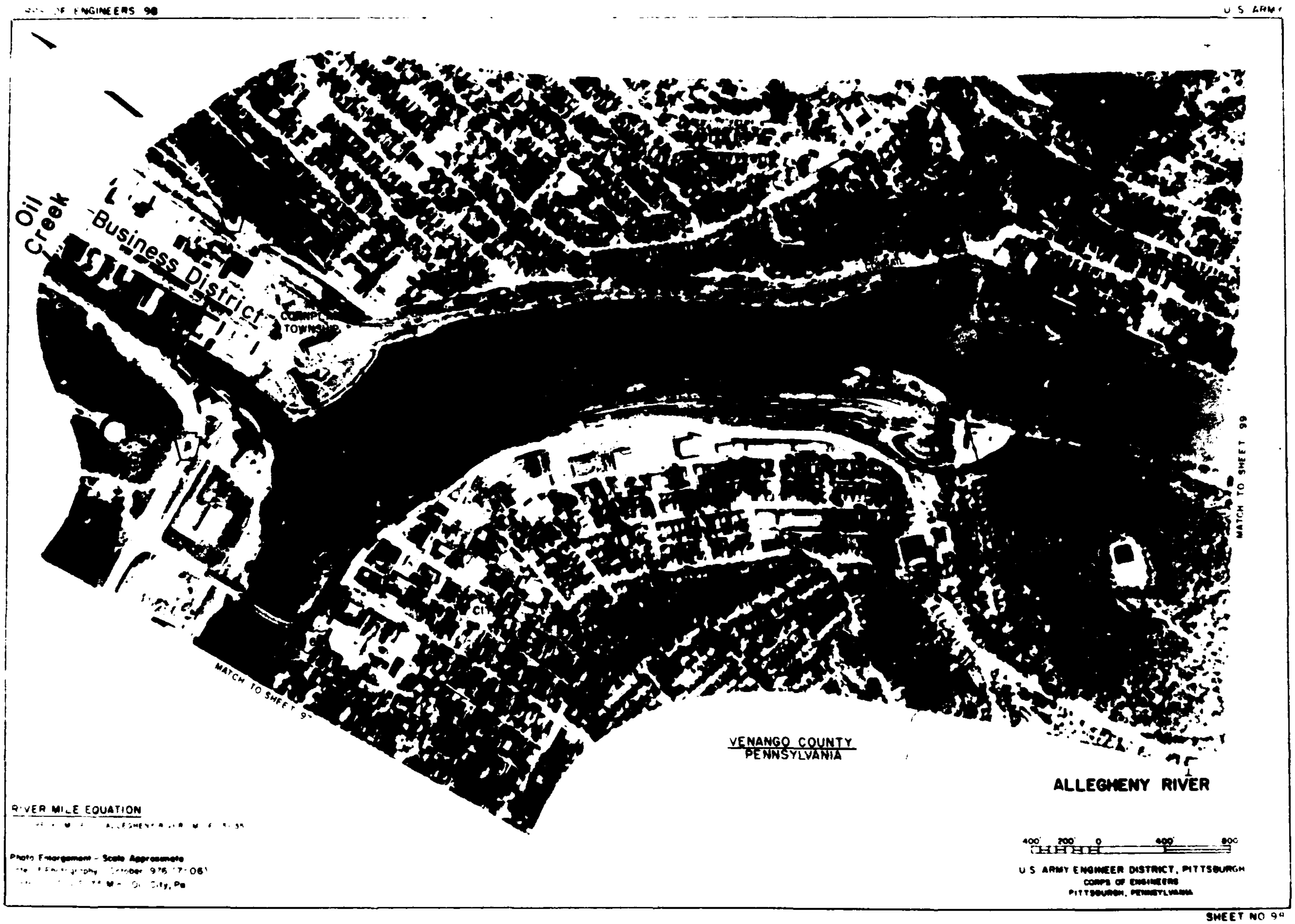
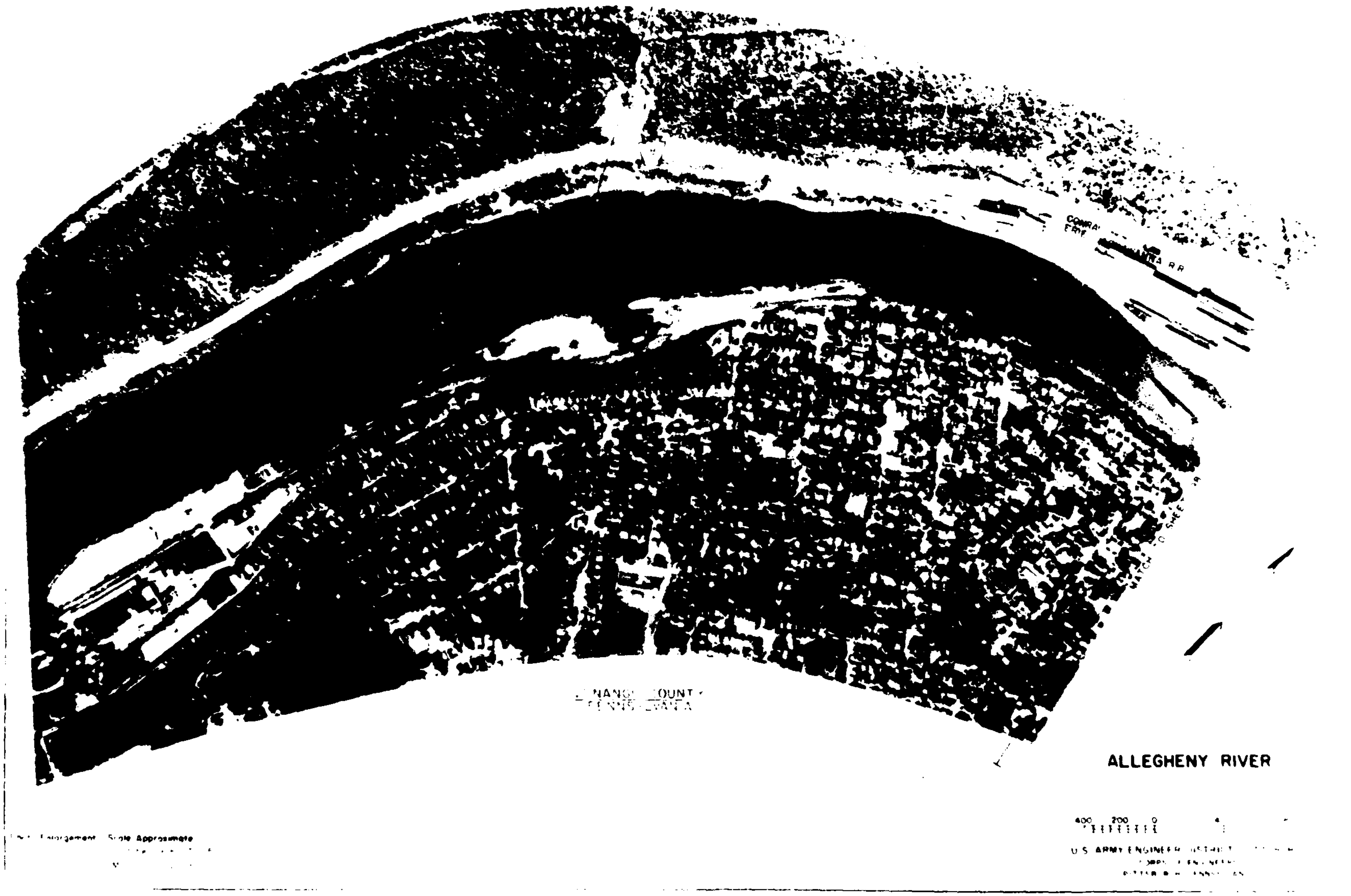
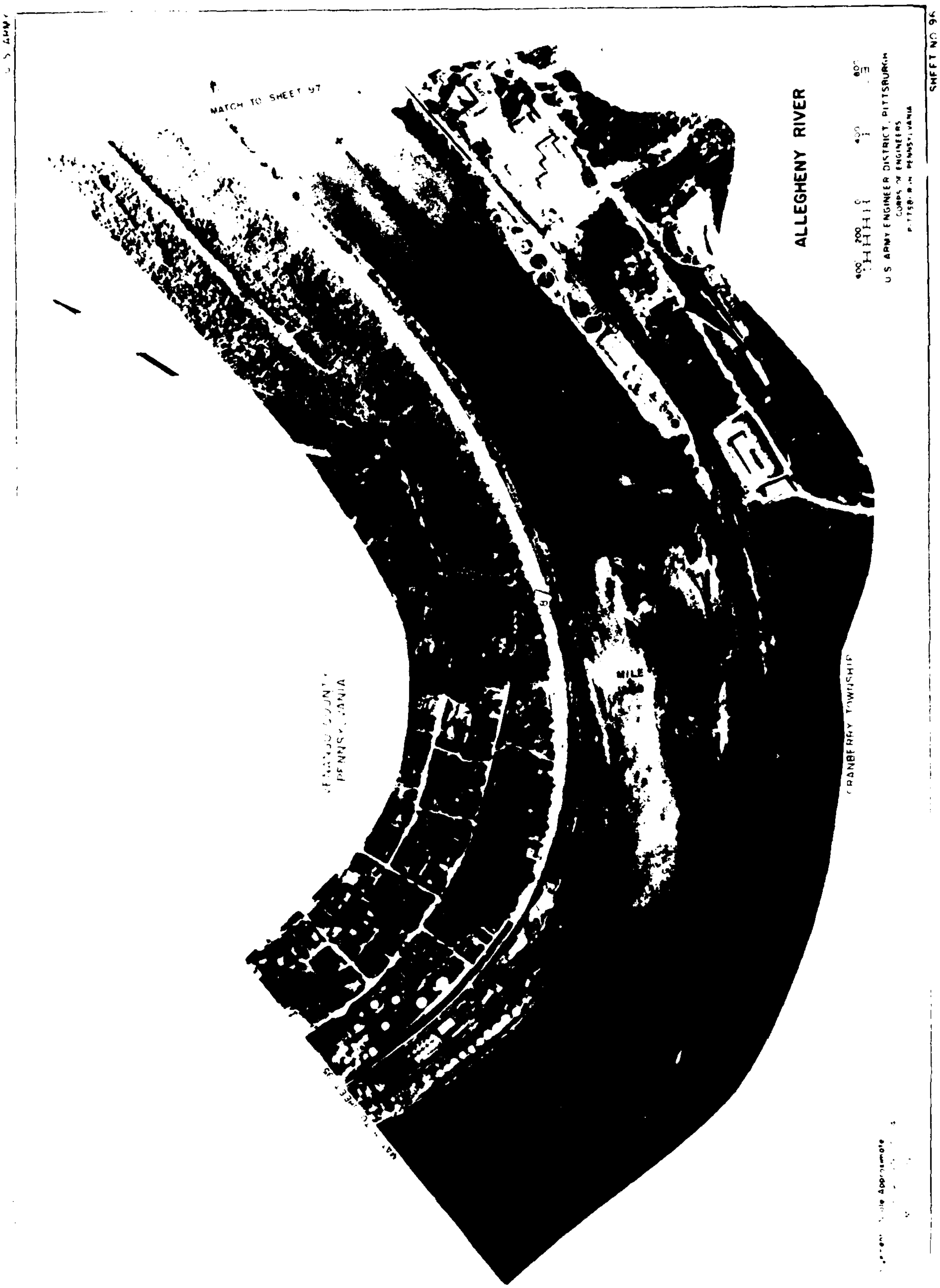


Figure 3. Air photos of Allegheny River near Oil City.

a. Mile 131.1–132.5.



b. Mile 129.7–131.1



c. *Mile 128.3–129.7*

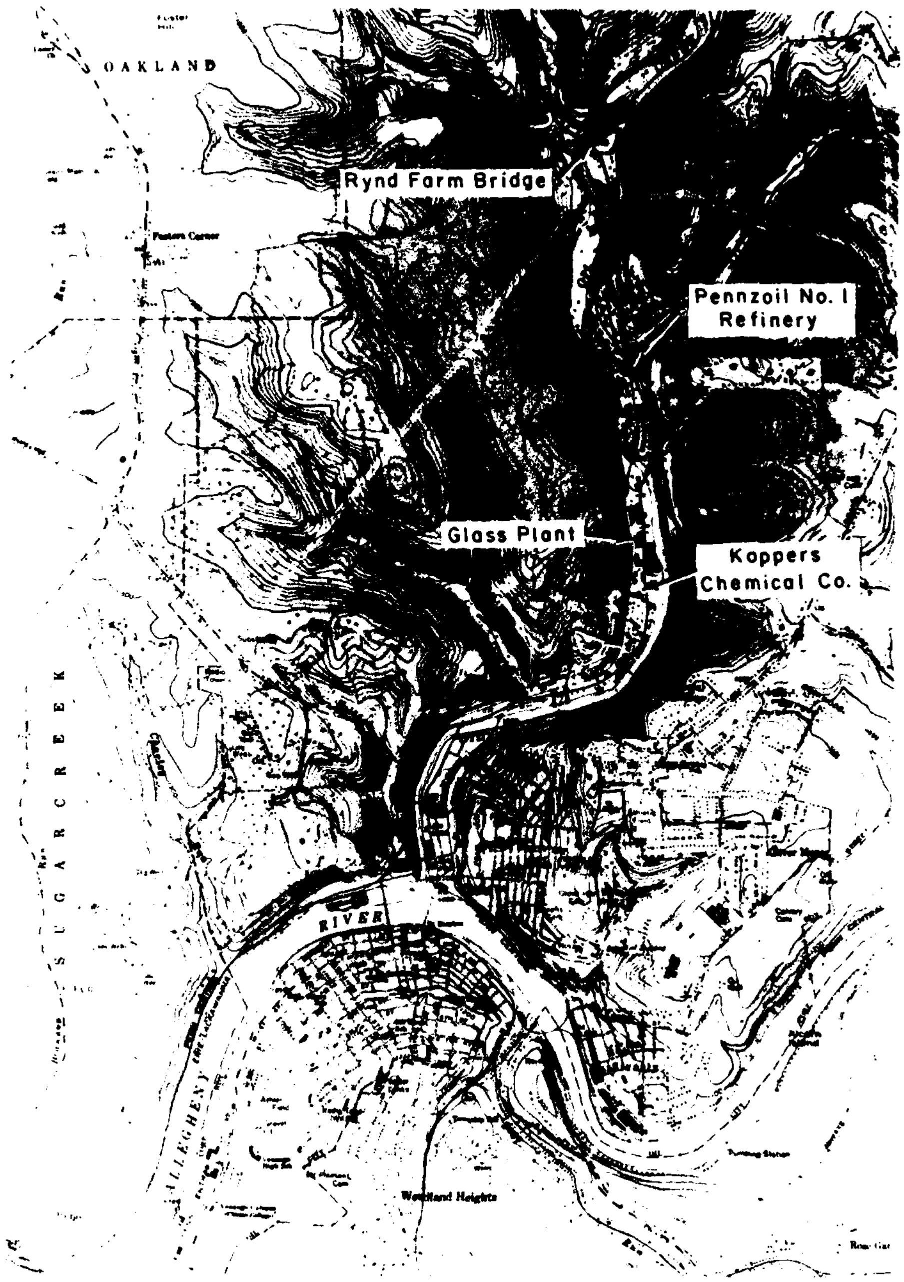


Figure 4. USGS map of Oil City.

up Oil Creek

Ice formation and jamming patterns were entirely different prior to the dredging operation. Ice jam flooding of Oil City occurred only when a jam was formed 11–23 km (7–14 mi) downstream. Allegheny River ice at Oil City and upstream consisted of a series of ice-covered reaches rather than the present full cover. When the ice broke up and joined the existing downstream jam, its backwater could reach Oil City and cause the creek to overflow its banks.

Appendix B contains stage frequency plots comparing ice jam flooding with open-water floods. Only ice jam events that caused Oil Creek to produce overbank flooding were considered. The data were adjusted for their incomplete record from the *Guidelines for Determining Flood Flow Frequency* (U.S. Water Resources Council 1976). The Allegheny River stage that produces overbank flooding of Oil Creek is the 100-yr open-water stage of 18 ft. Prior to dredging, the flow exceeded this stage about once every eight years. During and after dredging, flooding occurred practically every other year.

Breakup

Typically, the water levels of small streams such as Oil Creek respond sooner to snowmelt

Figure 5. Confluence of Oil Creek with the Allegheny River viewed from the north.

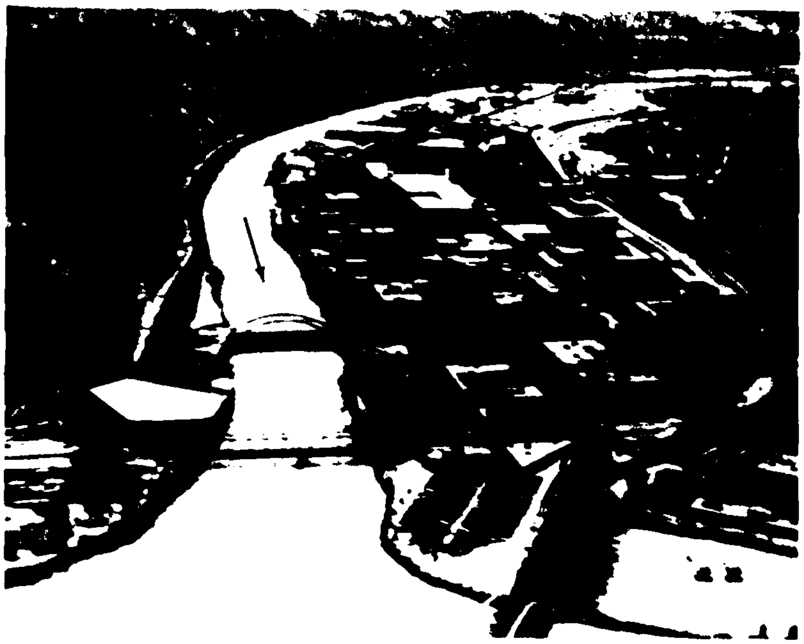


Figure 6. Confluence of Oil Creek with the Allegheny viewed from the south.

Figure 7. Highly turbulent flow of the Allegheny River at the confluence with Oil Creek.

Figure 8. Typical surface ice conditions on the dredged pool.

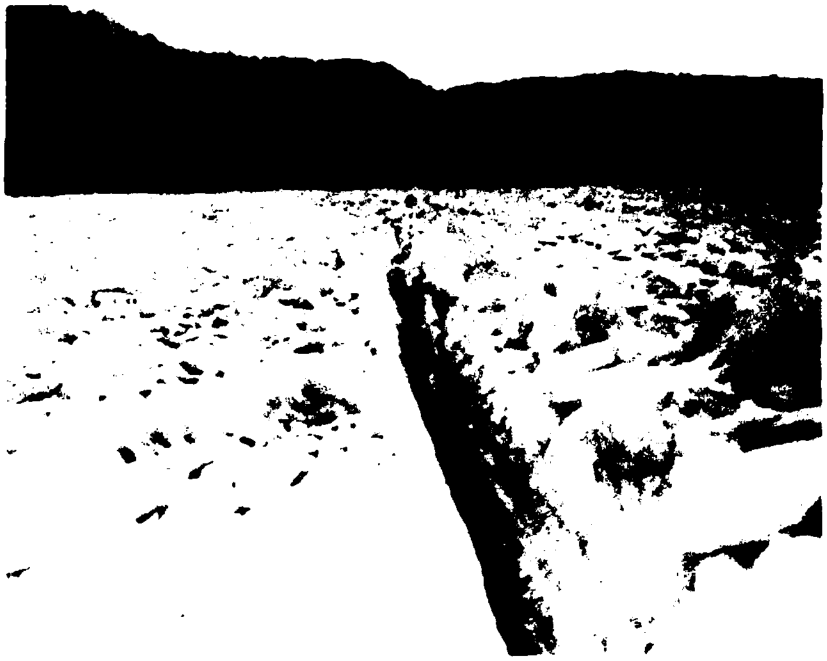


Figure 9. Ice shear line on the dredged pool.

and rainfall than those of large rivers. Because of this, Oil Creek's ice cover breaks up and runs before the river does. When this creek ice gets to the confluence, it has no place to go. The confluence area is already full of stable Allegheny River ice, which effectively stops the flow of creek ice. As a result it jams and, depending on the severity of the jam and the rate of runoff, Oil City can be flooded.

Two separate ice cover formations and breakups occurred on Oil Creek in 1980, during which the ice was monitored from the first indication of movement to the last. A warming trend during the week of 18 February, coupled with 13 mm (½ in.) of rainfall on the 22nd, caused the creek ice to run and jam at the confluence. Water levels came within 0.3 m (1 ft) of overbank flooding. This jam slowly moved onto and under the Allegheny River ice until late on 24 February, when the creek became ice-free. This event was followed by a small snowfall and a cold spell which allowed the creek to grow an ice cover again.

The creek ice ran once more on 8 March after another warm spell and 25 mm (1 in.) of rainfall. This was an orderly breakup with no indication of flooding. The river ice began its breakup on 9 March and continued through 12 March, again with no threat of flooding in Oil City.

During an ice run, the river ice and creek ice are transported quite well by their respective channels until they reach the confluence area. This reach of the Allegheny, from the confluence to the downstream edge of the deep-dredged pool, has ice thicknesses an order of magnitude greater than the upstream reaches and offers much greater resistance to breakup. The hydraulic slope in the dredged pool is relatively small, which indicates that flow velocities (and therefore shear stresses exerted on the bottom of the ice) are also less.

ALLEGHENY RIVER ICE CONTROL

The confluence and dredged pool areas should be kept free of the massive ice accumulations which currently develop. This could be accomplished if the ice cover or jam was artificially induced upstream of the confluence, preventing the frazil slush from being carried into the dredged pool. Forming a quick ice cover would eliminate the frazil production in upstream reaches and would reduce the amount of ice in the river system.

It appears that a floating ice-control structure would be successful in the vicinity of Allegheny River mile 131.7. Conditions upstream of this

point for approximately 275 m (900 ft) consist of surface velocities ranging from 24 to 80 cm s^{-1} (0.8 to 2.6 ft s^{-1}), with Froude numbers (based on depth of flow) of 0.07- 0.15 and river widths of 140-200 m (460-655 ft).

Requirements for solid ice block stability have been analyzed by many authors (Michel 1966, Pariset et al. 1966, Uzuner and Kennedy 1972, Ashton 1974, Larsen 1975 and others). However, their results cannot be directly applied to the case of a stable ice cover forming from frazil slush. Generally an upper limit for the Froude criterion (based on depth of flow) is 0.11, with 0.08 used as a conservative value. Most of the ice block stability work, whether using a Froude number based on the flow depth, ice flow thickness or porosity, leads to a critical velocity for ice cover formation of about 60-70 cm s^{-1} (2-2.5 ft s^{-1}).

We feel that these critical limits may be extended when dealing with frazil slush rather than solid ice blocks. Underturning or tumbling will not occur with a frazil slush pan although submergence may. Frazil slush will collapse and thicken rather than underturn and thus will be more stable.

A structure placed in the Allegheny should alleviate most of the problem. This structure would collect the floating frazil slush and establish an ice cover, thereby leaving the confluence and dredged pool free of any significant amount of ice. An ice cover will grow, quickly eliminating frazil generation upstream and resulting in lower water levels at the confluence. The effects of this structure on water levels upstream should be equal to or less than the effect of the present ice formation process. The ice cover or hanging frazil dam and its backwater effect will be formed approximately 4 km (2.5 miles) upstream from the present location.

With an ice cover formed above the confluence, Oil Creek should remain largely ice-free within the city limits. With no backwater effect on the Creek from the Allegheny River, velocities would be too high in this reach for a stable ice cover to form.

OIL CREEK ICE CONTROL

Oil Creek is capable of producing massive amounts of frazil ice, as much as 1.1×10^5 m^3 day^{-1} (1.5×10^5 yd^3 day^{-1}). A frazil-generating reach is shown in Figure 10. The creek velocities are too high within the city limits for a stable ice cover to form. The frazil generated upstream in the creek continues through this reach and into the Allegheny (Fig. 11). A stable cover is not formed on the creek within the city limits until the Allegheny has an ice cover extending up to the confluence. In 1980 the backwater effect of the river ice raised water levels in the creek by 1.2-1.5 m (4-5 ft), which made flow conditions in the creek favorable for a stable ice cover.

Initiating a stable ice cover

We feel that forming a stable ice cover 5.5 km (3.4 miles) upstream from the confluence would drastically reduce the quantity of ice which now collects in the creek. It appears that the major frazil-producing area is upstream of this location and that by quickly inducing a stable cover, further frazil production would be eliminated. Stream conditions at this proposed site are: mean discharge, 13 m^3 s^{-1} (450 ft^3 s^{-1}); velocity range, 45-55 cm s^{-1} (1.5-1.8 ft s^{-1}); flow depths, 0.3-1.1 m (1.0-3.5 ft); and stream width, 58 m (190 ft).

Downstream of the proposed site, the creek banks are heavily developed, with two oil refineries, a glass factory and a chemical plant. These industries use the creek for disposal of their thermal effluent. This heat load is significant for reducing frazil production or deteriorating an existing ice cover.

Thermal suppression

Ashton (1979) developed a mathematical model to predict the effects of thermal effluents in suppressing river ice. This model can be applied to Oil Creek. Assuming that the effluent is fully mixed and is introduced to the stream at a point where the water is at the freezing point, the reach of the stream X in which the water will remain above the freezing point may be expressed as

$$X = \frac{-\varrho_w C_p \bar{V} \bar{D}}{h_{wa}} \ln \frac{-T_a}{T_{w_o} - T_a}$$

where ϱ_w = water density (kg m^{-3})

C_p = specific heat capacity (W s kg^{-1} $°C^{-1}$)

$\bar{V}$ = mean flow velocity (m s^{-1})

$\bar{D}$ = mean flow depth (m)

h_{wa} = heat transfer coefficient from the water to the air (W m^{-2} $°C^{-1}$)

T_a = mean air temperature (°C)

T_{w_o} = water temperature of the stream at the heat source (°C).

Figure 10. Frazil production in Oil Creek.

Figure 11. Frazil slush flowing freely from the creek into the river.

We can apply this to Oil Creek by assuming that the ice control structure is in place and that the heat load is introduced just downstream of the structure. For example, we can use these reasonable estimates of on-site conditions:

$\varrho_w = 1 \times 10^3$ kg m^{-3}, $C_p = 4.22 \times 10^3$ W s kg^{-1} °C^{-1}, $\bar{V}$ = 0.5 m s^{-1}, $\bar{D}$ = 0.6 m, h_{wa} = 20 W m^{-2} °C^{-1}, and T_a = -5°C (mean of Dec–Feb 1976 through 1980). The equation shows that a 5.3-km (3.3-mile) reach of the creek would remain above freezing if T_{w_o} = 0.4°C. Oil Creek should remain ice-free from the structure downstream to the confluence of the Allegheny River.

The heat load needed to raise the water temperature to the required 0.4°C from 0°C can be calculated from the equation

$$P = \varrho_w C_p Q T_{w_o}$$

where P is the heat load (W) and Q is the stream discharge (m^3 s^{-1}). Using the mean discharge of 14 m^3 s^{-1}, the required heat load is 23.6 MW. The reported mean heat load as of 1980 was 4.2 MW, or approximately 20% of that required. However, with the structure in place, the large quantities of frazil generated upstream would be unable to pass to the lower reach, and Oil Creek, within the city limits, would be relatively ice-free.

CONCLUSIONS

We feel strongly that most Oil City ice jam flooding can be alleviated. Before attempting any solution, we need to look at these ideas very closely. More field and laboratory research is needed. We feel that a small-scale field demonstration and research project in Oil Creek would give us the most useful information. An ice control structure in Oil Creek is planned for the winter of 1980–81. This installation is the most logical step towards alleviating the ice jam flooding problem at Oil City. Controlling the creek ice will provide us with the data required to evaluate the effects of the Allegheny River ice alone. This in turn will show us whether the river ice must be controlled. We anticipate that both the river ice and the creek ice will have to be controlled (and possibly other methods of control introduced) to accomplish a complete solution.

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APPENDIX A: REPRESENTATIVE CROSS SECTIONS OF THE ALLEGHENY RIVER AND OIL CREEK (LOOKING DOWNSTREAM).

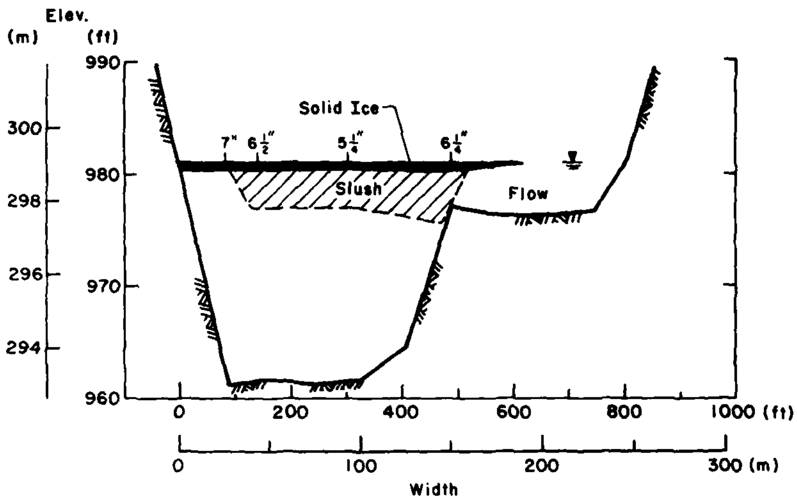

Figure A1. Allegheny River, mile 129.36 (5 February 1980).

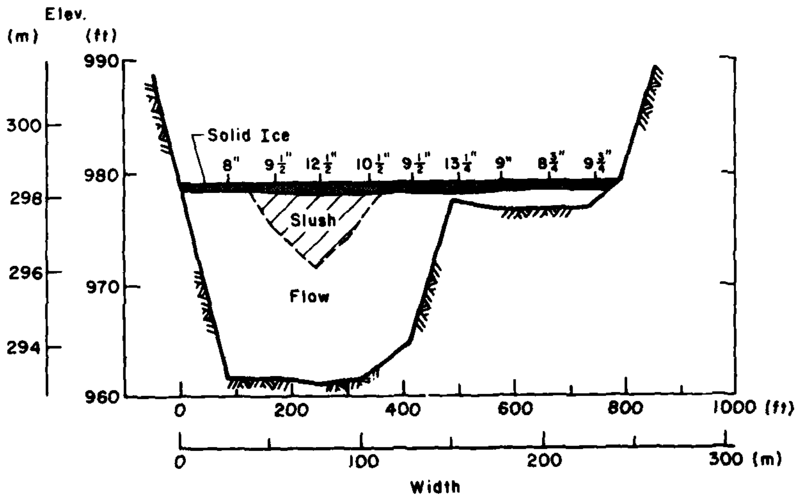

Figure A2. Allegheny River, mile 129.36 (20 February 1980).

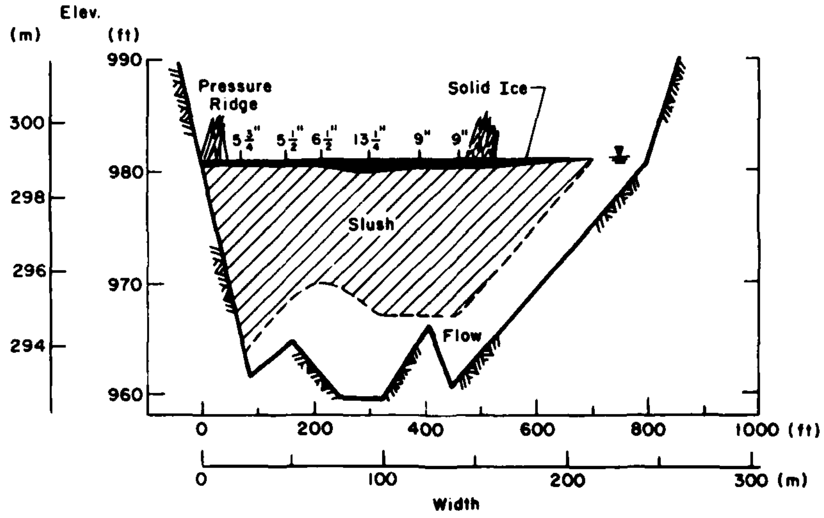

Figure A3. Allegheny River, mile 129.88 (5 February 1980).

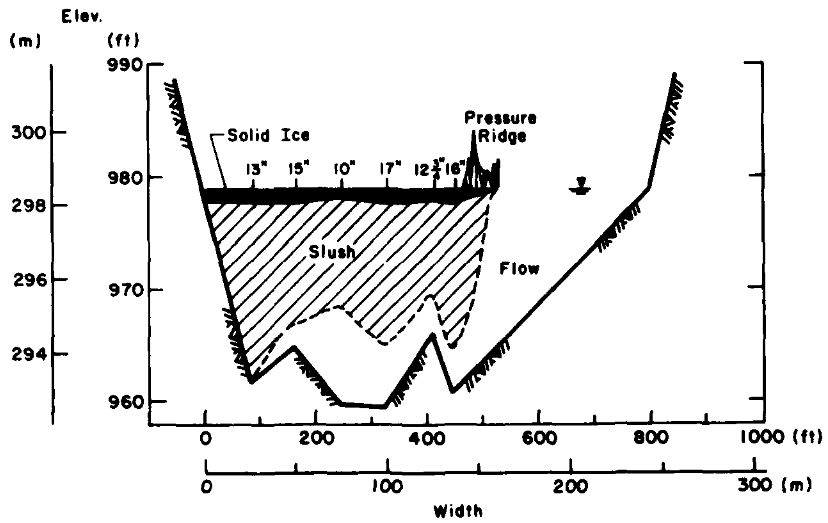

Figure A4. Allegheny River, mile 129.88 (21 February 1980).

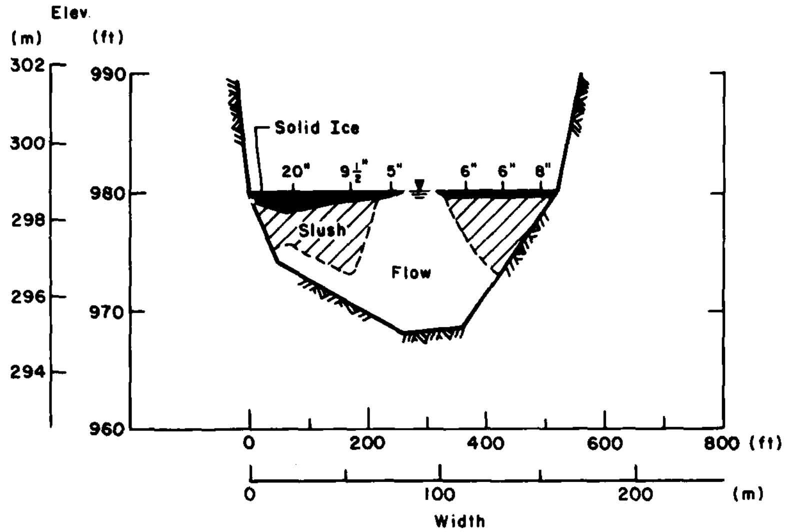

Figure A5. Allegheny River, mile 130.64 (6 February 1980).

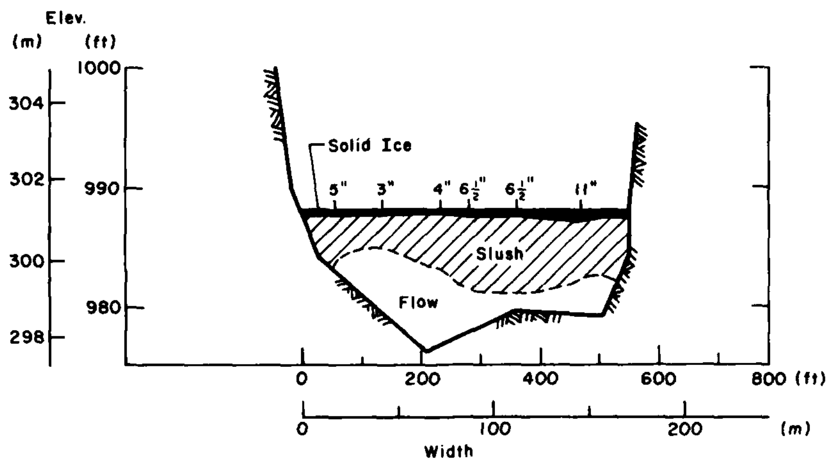

Figure A6. Allegheny River, mile 131.23 (6 February 1980).

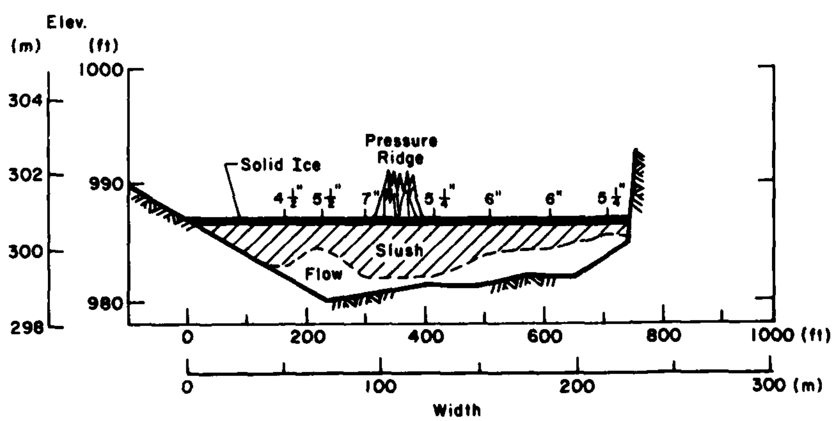

Figure A7. Allegheny River, mile 131.36 (6 February 1980).

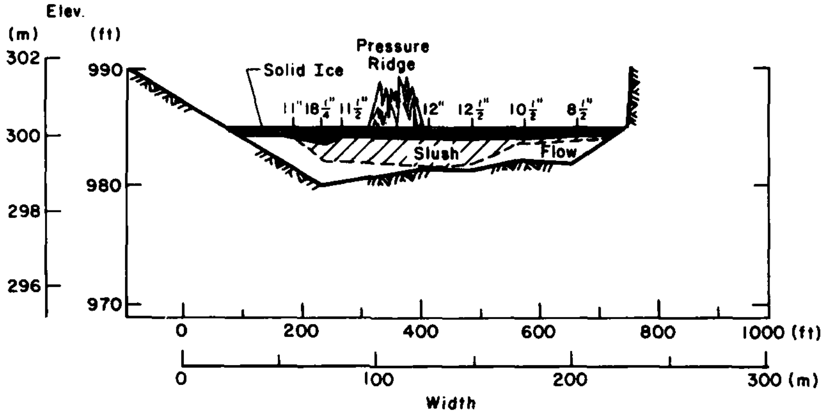

Figure A8. Allegheny River, mile 131.36 (21 February 1980).

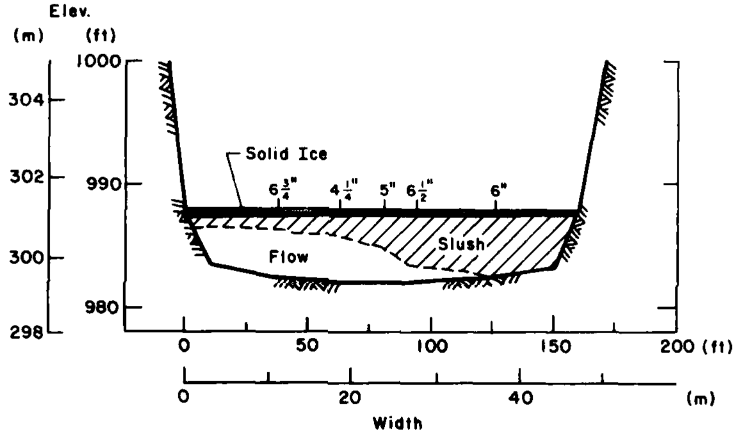

Figure A9. Oil Creek, mile 0.20 (7 February 1980).

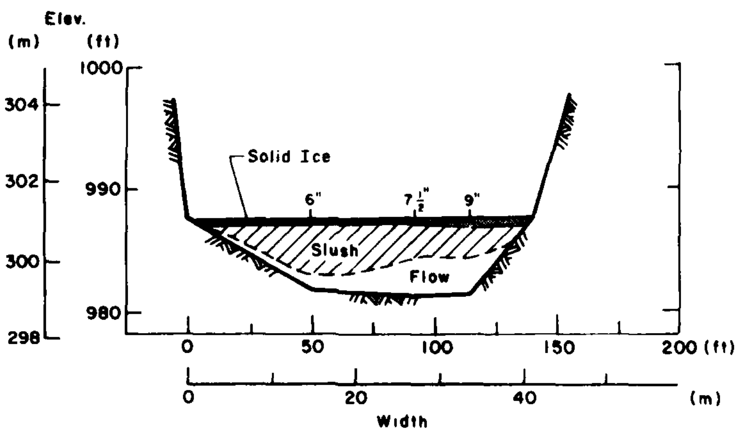

Figure A10. Oil Creek, mile 0.16 (7 February 1980).

APPENDIX B: ALLEGHENY RIVER STAGE-FREQUENCY PLOTS RELATING ICE JAM FLOODS TO OPEN WATER FLOODS.

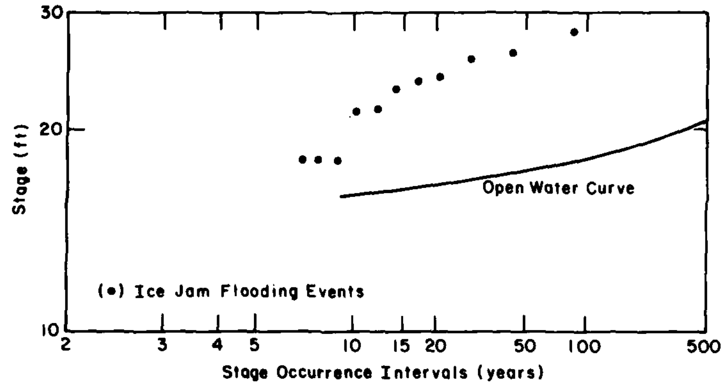

Figure B1. Ice jam floods prior to dredging (11 events in 86 years, 1866–1950).

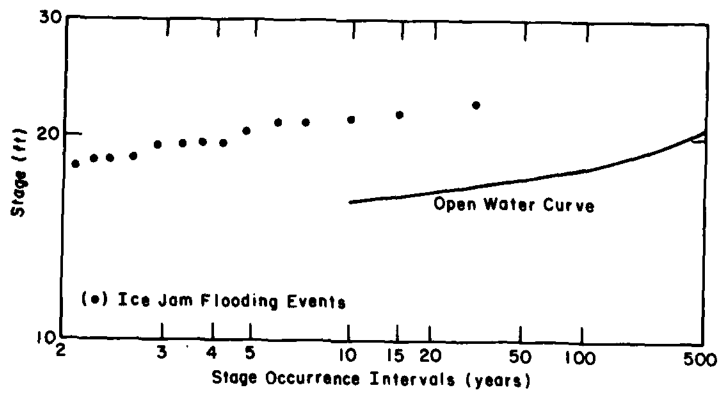

Figure B2. Ice jam floods during and after dredging (14 events in 29 years, 1951–1979).